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New Design of Smart Socket Modules for Smart Home Applications

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Abstract: The intelligent Home is an important realization of the environments of brilliant electricity. The designed module is to be considered using in smart home applications where electrical safety is required. This can be achieved, by measuring electrical current, voltage and the power of connected device. The electrical parameters are monitored and controlled by client application software running under widely used internet browsers. The module is also monitors the status of the plug and the surrounding temperature of the socket.

I. INTRODUCTION

Energy plays vital role in our life, covering all aspects ranging from homes, businesses, health, education and economy. The involvement of electrical equipment is essential in all services and sector for their daily usage due to adverse atmospheric and environmental change that requires the need of energy in abundance. Developed countries have excessive energy availability. Whereas, developing countries like Pakistan are facing energy shortfalls. Hence, for developing countries energy conservation has become inevitable that can be achieved by exploiting the new technologies (i.e., smart socket [1], the incorporation of artificial intelligence [2–4]).

The paper focuses on smart socket, whereas the incorporation of AI techniques will be added in the future work. Smart Socket provides an efficient solution to conserve energy for any closed environment such as homes, offices, and institutions etc. However, it is important to consider the limitations of deploying the smart socket system into account. Smart socket technology uses existing communication techniques (e.g.,Wi-Fi,ZigBeeetc.) for communication purpose between the equipment. Each equipment is equipped with a mechanism that can control the energy consumption by turning the node between on and off states and report their states to the master entity (e.g., mobile phones and applications).

Generally speaking, the master entity is responsible to provide the consumer an easy Sensors (F.3) Sensors play an important part in building smart energy conservation systems as they are responsible to interact with the environment smartly and intelligently [12]. A variety of sensors are being used to sense different parameters and perform intelligent control according to these parameters. For instance, Motion or occupancy sensors can sense the presence of a human in a closed environment and perform intelligent light control accordingly. The light sensors are used to measure the intensity of light and perform light dimming or switching the light in on/off state. Finally, temperature sensors are used to measure temperature to maintain the temperature of a closed environment (e.g., room) [12,13]. Note that sensors and nodes are the words that are used interchangeably throughout the document.

1.3 Load Monitoring and Management (F.4)

Load monitoring and its management are important challenges that need to be considered while designing the smart energy system in order to achieve better performance. For instance, current sensor or metering ICs are used to sense and measure the live current passing through the circuit and can provide power monitoring and management mechanisms[14]. access to monitor and control the consumption of energy that equipment utilized. In other words, the consumer can monitor and control the equipment locally as well as remotely via the internet through mobile phones, which can save up to 40% of energy [5], and thus can drastically reduce the shortage of energy in developing countries like Pakistan. Following are the important factors (F), which should be considered in the evaluation and design the smart socket technology.

1.1 System Design(F.1)

The system design of a smart energy conservation system should have capabilities to monitor the energy load, as well as intelligently control the power of the system. In view of the aforementioned capabilities, different system designs have been proposed in the literature. For instance, [6–8] have incorporated the monitoring and control capabilities in which data is transferred to a control panel for analyzing and comparison purposes. Some systems also incorporate remote facilities to perform remote monitoring and controlling through smart phone applications [9].

1.2 CommunicationTechniques(F.2)

For the transfer of data in smart energy conservation system, a communication technique is required to enable the system to communicate with corresponding nodes or equipment. Wired, as well as, Wireless techniques are employed to fulfill this challenge and create a network of the smart system [10]. Since the focus of this paper is on the use of wireless techniques to conserve the energy; therefore, some fits examples are Bluetooth, ZigBee communication, and Wi-Fi communication [11]. It is notable that each technique has its own pros and cons in terms of capacity, quality, coverage and cost factors Scalability(F.5)

To meet the future requirement of electricity it is important to design smart systems that can provide the scalability in systems by extending the size of smart systems to accommodate a greater number of users. Generally speaking, smart systems can be divided into three sizes with respect to the number of users. These include wide area, medium size, and small size[15].

1.5 Cost Effectiveness (F.6)

As discussed, that the requirement of energy conserving smart systems is inevitable but it cannot achieve its significance unless a cost-effective solution is proposed. However, a trade-of should be set to achieve the optimal smart energy system, which also serves as a cost-effective solution [11]. The rest of the paper has five sections. Section2 provides the details of IoT-enabled smart applications communication infrastructure. Section3 provides the detail of the proposed design. Section4 provides a scenario and the implementation details. Section5 provides results. Whereas, Sect.6 provides the conclusion and highlighted the future work that may give the extension of this proposed work.

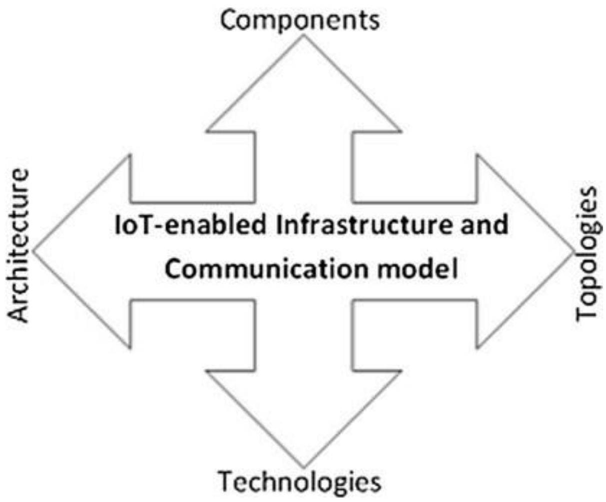


Fig.1 Dimensions of IoT-enabled smart application

II. IOT- ENABLED SMART APPLICATIONS

Communication Infrastructure IoT enabled system means the connection between devices, which also provide accessibility to users from anywhere and anytime[16]. Similarly, IoT-enabled smart home provides an opportunity to end users to access different devices of their homes directly by means of communication medium (i.e., wired or wireless). The infrastructure and communication model used in the existing literature for the implementation of IoT-enabled smart application relies on four distinguished dimensions, namely, components, architecture, topologies and technologies, which can be shown in Fig.1. The description of each dimension is discussed below in brief details.2.1 IoT- Enabled Smart Application: Components. The components used to make IoT-enabled smart applications can be categorized into smart hardware, software platforms, and traditional hardware as shown in Fig. 2. Generally speaking, the smart hardware includes sensors, processors, transmitters, and receivers; whereas, the software platform includes operating system, software codes and database; and finally, the traditional hardware includes electrical and electronic equipment (e.g., lights, fans, television, fridge and air conditioner) [17].

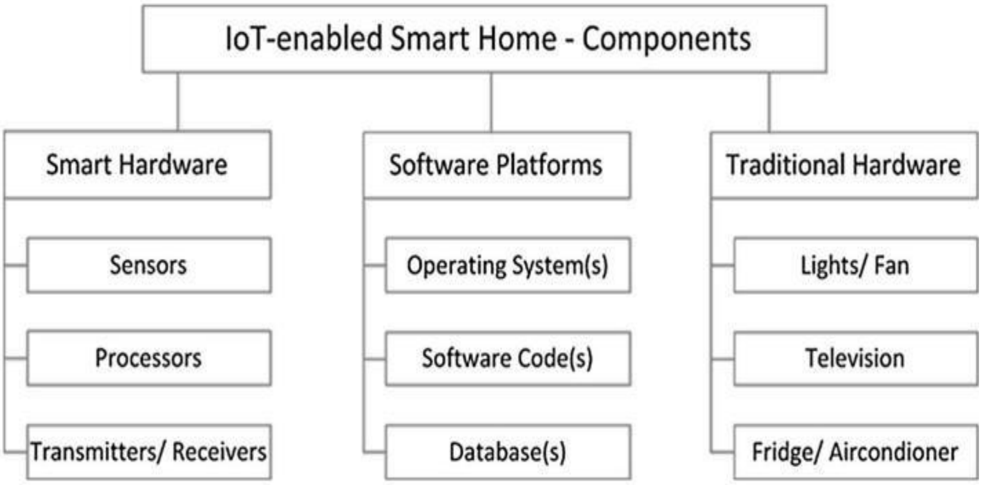
2.2 IoT- Enabled Smart Applications: Architecture

The architectural platforms of IoT-enabled smart applications can be classified into two types that are centralized and decentralized [18]. In a centralized IoT architecture, components are responsible to provide data, which will be retrieved by a centralized entity (e.g. cloud services). All components are connected with the centralized entity by means of the internet. The centralized entity is responsible to acquire information from components located at various locations within the network.

Whereas, in a decentralized (or distributed) IoT architecture, the entire IoT network is interconnected in which components have the ability to retrieve, process, combine and provide information and services with each other. In other words, intelligence.

2.3 IoT- Enabled Smart Application: Topologies

The topological structure of IoT-enabled smart applications can be divided into three broad categories. These are star, mesh, and hybrid [19]. In star topology, the components are connected with the central entity, and so it always follows centralized architecture. In mesh topology, each component is connected to every other component, as well as to the servers and databases.



2.4 IoT- Enabled Smart Application: Technologies

The existing communication technologies that have been used in IoT- enabled smart applications can be classified with respect to long-range coverage area and small-range coverage area.

Cellular networks, Sigfox, and Nerul are the communication technologies that covered long range areas; while,Wi-Fi, 6LowPAN, and LoRaWAN are the communication technologies that covered small-range areas [18–20]. Thus, it is important that the IoT-enabled communication infrastructures have the ability to provide seamless accessibility to end-users in order to reap the benefits offered by IoT and its enabled applications.

III. PROPOSED DESIGN

This section describes our proposed design model, which comprises three major sub systems that includes sensing sub system, communication sub system, and control subsystem. Firstly, the sensing sub system sensors are attached to Arduino board, which we named as a smart board. Secondly, the communication subsystem is responsible to provide a communication between the subsystems. The communication is taken place using a wireless sensor network (WSN), and therefore we named as WSN communication. Lastly, the control subsystem is responsible to provide monitoring in order to make decisions to preserve the energy (or power) on the basis of values observed by the sensors. Figure 3 depicts the functional diagram of our proposed design in which it is visible that communication subsystem is acting as a bridge in between of sensing subsystem and control subsystem. The detail of each subsystem is presented below in the form of the block diagram and working.

a. Smart Board

The smart board is responsible to provide a mechanism for switching, monitoring and controlling of lights and other electrical equipment by means of sensors outcomes. It mainly comprises on Arduino UNO microcontroller-based board that can connect with other external devices with the help of input/output (I/O) pins. In this work sensors and switches are external devices and connected with Arduino UNO board. More specifically, the smart board is providing an interface and its circuit, interfacing with WSN subsystem via YUN shield, relays and a logic circuit for switching the sockets ON/OFF, and switch button to change modes of operation. Figure 4 depicts the block diagram of a smart board. Smart board is working in a way that Arduino UNO is connected with YUN shield, which enables the remote access to the board to ensure the controlling of lights and other electrical equipment. Arduino UNO is responsible for gathering of sensors’ data and to forward that data to the server.

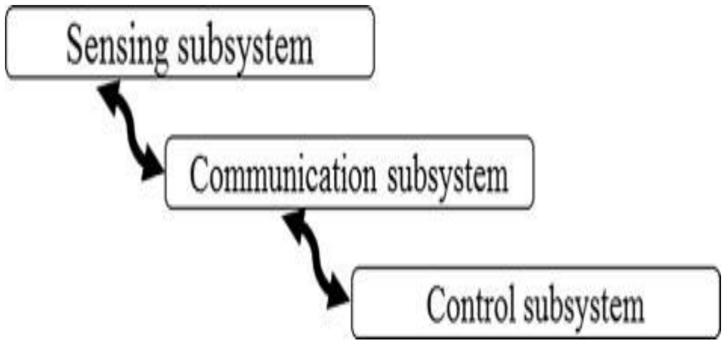


Fig.4 Smart board block diagram

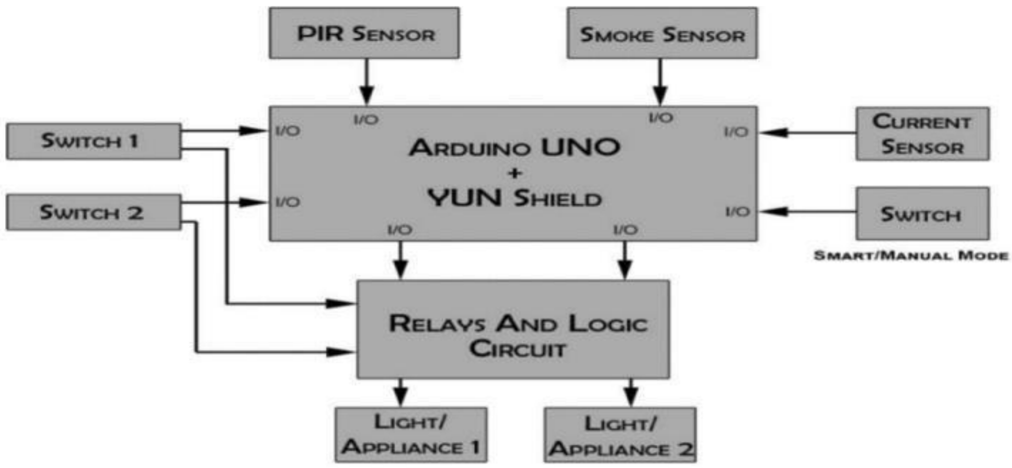


Fig.5 Communication sub system block diagram

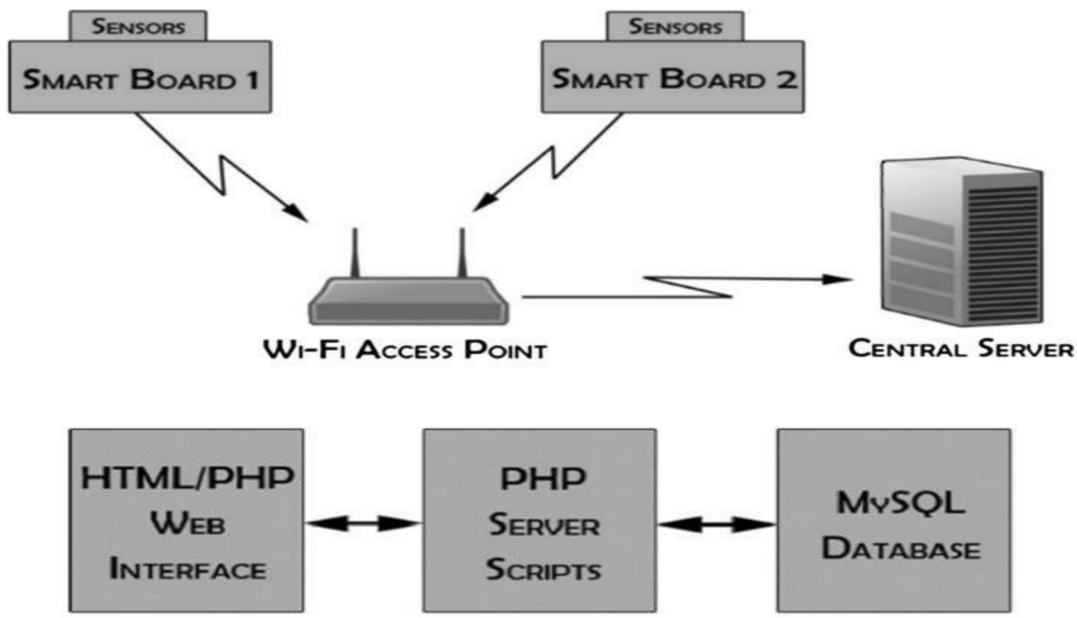


Fig.6 Central server block diagram

Based on the decision made by the server the Arduino board instructs the light sensor to do switching in between on and off states. The relays and logic circuits are used to turn the respective lights in on and off states. The sensors attached to the smart board are a current sensor, PIR sensor, and smoke sensor. The current sensor is used for power consumption monitoring and placed inside the smart board. PIR sensor is used for human presence monitoring and placed outside the board at a position that can cover the whole room. Whereas the smoke sensor is used for smoke detection in the case of the fire situation. Whenever the smoke detector detects smoke, it sends a signal to the smart board, which cut of the power immediately to prevent any further damage. Thus, the smart board allows automatic and remote switching of equipment with the help of sensors and can save more energy than the manual mode. The smart board provides a system design (F.1), and the inclusion of sensors (F.3) as well.

b. Communication Subsystem

As discussed earlier that the WSN network is used as a communication technique (F.2) to provide a linkage between sensing subsystem (i.e., smart board) and control subsystem (i.e., central server).The smart board along with sensors attached to it is connected to a central server via wireless access point as shown in Fig.5.The access point is providing a link through which all the sensors' data is stored in a database of a central server.

c. Central Server

The central server is a computer that runs continuously and reserved for collecting all power consumption data from the aforementioned sensors connected to different smart boards. More specifically, the central server is responsible for the management and remote monitoring (F.4) of all the smart boards. A local web server along with a database would be hosted on the server; the hosted website is used for interfacing with the smart boards. The hosted website on the central server is designed using HTML and PHP languages, which provide a web interface and server scripting features as shown in Fig. 6. MySQL database is used for storing and comparing different sensor values from different smart boards.

For instance, the website can be used to monitor the real-time power consumptions of different rooms in a home, which subsequently allow the switching of lights in on and of states. The website has several pages and each page is for a separate room. Real-time power consumption data can be collected from the database on the central server, and the value is updated after every 10 s.

The website is providing another feature in which the electrical equipment installed at home can be switched on and off by using the button provided on the website. This option is integrated for enabling the remote controlling of installed electrical equipment and can be done by using an application (or API) by calling PHP script, which instructs the YUN shield to turn on/off the power socket. Thus, the central server provides an option for the consumer to monitor real-time power consumption through which consumer can check and control the current status of light and electrical equipment from the remote location.

IV. IMPLEMENTATION DETAILS

This section describes the scenario, which we have implemented using hardware and software. The hardware components are the power supply and relay circuit, a central processing unit, smart/manual switch and logic circuit, current sensor and comparator circuit, switch board, PIR and smoke sensor, and cooling fan.

Whereas, software refers to a piece of code that calculates the energy conservation as well as maintain the database. This implementation scenario is applicable and suitable for home and residential purpose and can be extended to industrial scale at the later stage. The sub sections include implementation scenario and modes of operation.

a. Implementation Scenario

As discussed earlier that at this preliminary stage we have implemented this project for residential and home users. Hence, a scenario is considered for a small home, which has 3 rooms, and a corridor. Out of 3 rooms, one small room is reserved as a server room where the central server is installed; while 2rooms (i.e., room 1 and room 2) having the same size are used as a place where 2 smart socket boards are installed. The wireless access point is placed in the corridor.

It is to mention that the corridor and the server room are not under smart sockets functioning. The central server received the smart socket's data via the access point. The implementation scenario diagram can be shown in Fig.7. Also, for the comparison purpose, a similar scenario is adapted for the manual procedure, which is a traditional (or manual) method that we used in our daily routine.

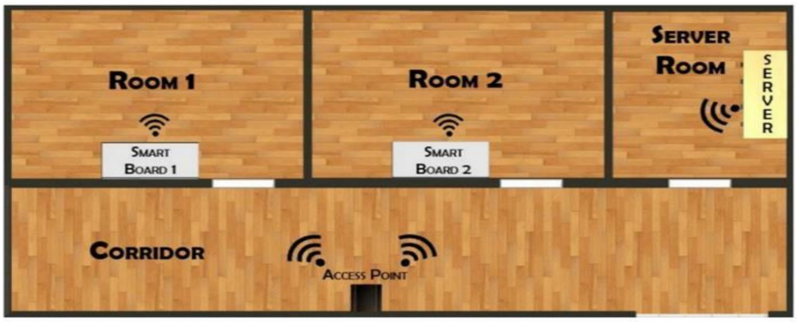


Fig. 7 Implementation scenario

b. Modes of Operation

This project has three modes of operation that allow users to select any mode in accordance with the desire and needs. These are the smart mode, manual mode, and restricted mode. The consumer can select between smart mode and manual mode by using as which button on the smart board, and for the restricted mode consumer needs to interact with the central server. Smart mode is one of the main modes in the smart socket that can provide the smart functioning (i.e., switching of unused lights automatically, power consumption monitoring, controlling of lights and equipment remotely through a central server, and smoke detection and cut-of power in case of fire situation). For instance, the PIR sensor is continuously detecting human presence in the room and if the sensor has not detected any human presence then the sensor instructs the Arduino YUN shield to turn of all lights in the room in order to conserve the energy. Whereas, restricted mode restricts the number of lights and equipment with respect to the predefined power threshold level. A central server is used to select which switches have to be restricted and when the restriction is applied no one is allowed to turn on that switch by any means (i.e., manually, remotely etc.). This mode helps to identify and turn of that equipment that is consuming more power. The manual mode suspends all smart functions in which the user uses the switch board to manually switch the lights and equipment in on and of states. However, the use of this board is only applicable if the smart board is not functioning well (e.g., in case of Arduino board failure). At the end of this section, we would like to highlight the main features that we have offered in this project, which include:

Energy conservation through autonomous control of lights based on sensor inputs

- Remote controlling of lights and appliances through the Web server
- Power consumption monitoring and reports
- Load detection of each individual loads
- Restrict lights and appliances switch wise
- Restrict an appliance from being turned on based on maximum power
- Cut-of power to all switches in case of fire situations
- Android application to interact with the web server through a smart phone.

V. RESULTS AND DISCUSSION

This section describes the test results that have been achieved in this project while considering three cases, which are related to modes of operation that defined earlier. The cases are the smart mode, restrictive mode, and manual mode. Below the description of each case is discussed along with their respective figures.

a. CaseI: Smart Mode

In this case, we tested the smart functionality of our project in which two lights of 60 W and another equipment of 100 W are connected with our smart board. Within a smart mode, the central server is also tested and able to monitor an approximate value of200 W on the screen. Apart from that, we have successfully tested the remote option through which lights and electrical equipment can be switched into on and off states (or vice versa) by using the central server. It has been also observed that the smart mode is able to detect all three loads individually using “Load Detection” feature successfully. Furthermore, we have also applied restriction case that will be discussed in the next case. Note in Fig.8 the
Auto mode is representing the smart mode

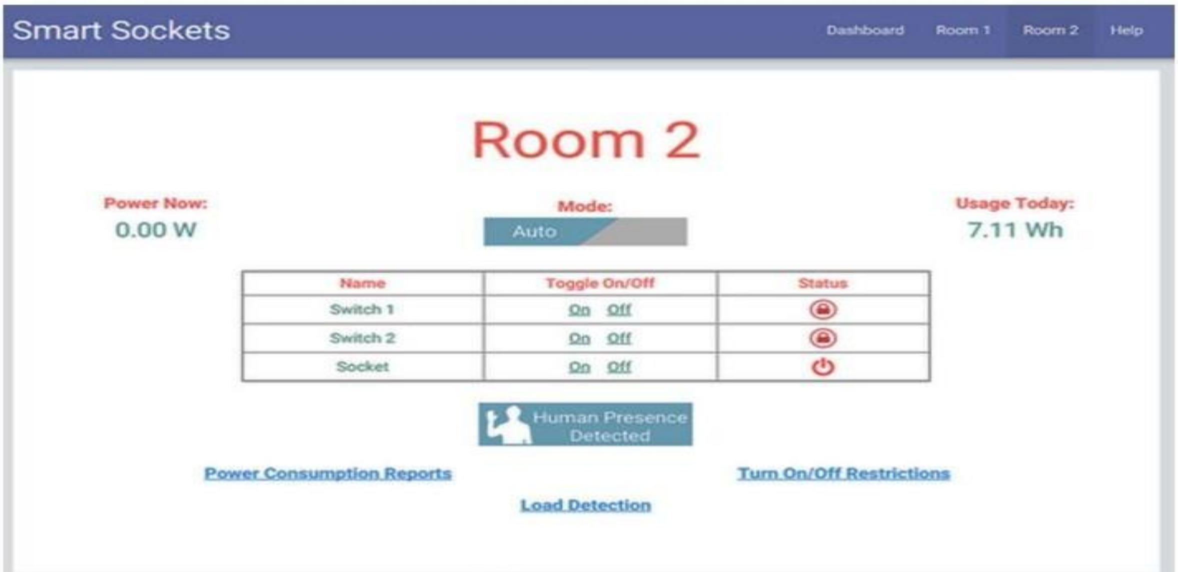


Fig. 9 Restrict by switch

Fig. 10 Restrict by maximum load

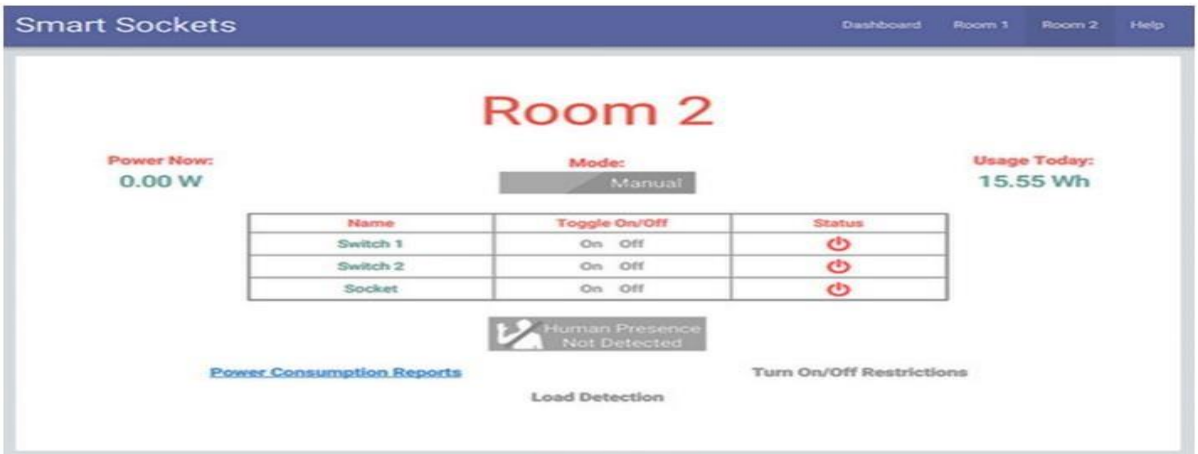


Fig. 11 Manual mode

5.1 Case II: Restrictions

Restricted mode is an important feature of this project that permits the user to control electrical equipment installed in the home. Thus, in this case, we have applied restrictions to check this feature of our project by considering two restrictive cases. In first restrictive case, we have applied restrictions on two switches (i.e., switch 2 and switch 3) and named it "restriction by switch". After restrictions are enabled on switch 2 and switch 3, the user cannot be able to turn on these switches either by manual method nor remotely. However, once restrictions are removed the user can be able to turn the switches in on and off states in accordance with user's requirements. Whereas, in second restrictive case, we have applied restriction on a socket in which the socket will be turned off if its power load exceeds to 300W and named it "restriction by maximum load". For testing purpose, we plugged in a hair dryer into a socket that consumes more than 300 W, but hairdryer fails to be turned on due to the restriction set on the socket. Later, we have plugged-in equipment that consumes lesser power than 300 W and noted that the equipment works perfectly. Figures 9 and 10 depict the two cases discussed in case II.

b. Case III: Manual Functioning

In this case, we switched to a manual mode in order to check if remote and smart functioning is still working or not and found that as soon as we switch to manual mode all smart functions disabled themselves, which include remote controlling, sensing, power detection and restrictions. However, the database running on the central server and provides monitoring statistics of power consumption utilized in the manual mode. Figure 11 depicts the manual mode, which disabled the smart mode and all its functions.

c. Energy Consumption and Conservation

The system is implemented in the rooms of two senior faculty members; they are engaged in other activities like meeting and evaluations besides teaching. As they frequently leave their rooms which require additional attention to switch OFF loads and re-on them after arriving. Considering a human effort switching of the Lights and Fans of rooms while leaving is not so punctual. Most of the time in a hurry or urgency they might leave rooms with electric load ON, which effects on the monthly consumption but not quite enough towards energy conservation. So, a single room consists of a Tube lighting fixture of 04TL524W840HO type tubes and a ceiling fan of 4820-1/48" type commercial ceiling fan. Each light is of 24W [21] and a ceiling fan is of 86 W [22], which means each room consists of a Fixture of 04 tubes and ceiling fans which is 24 × 4 = 96 W for lights and 86W for a ceiling fan, summing it all up equals to 182W per room. For two rooms it will be the load of 182 × 2 = 364 W. Mathematically speaking: L Tube is Load of a single tube in watts LFisLoad of Fan in watts. There are 04 tubes fixed in each room;

LT-Tube is total load of all 04 tubes in a room (Eq.1)
LT-R is total load (04 tubes + fan) per room in watts i.e.Eq.2
LT is the total load on the system i.e.Eq.3

$$L_{T-Tube} = 04 \times L_{Tube}$$
$$L_{T-Tube} = 04 \times 24\ \text{W} \quad (1)$$
$$L_{T-Tube} = 96\ \text{W}$$

$$L_{T-R} = L_{T-Tube} + L_F$$
$$L_{T-R} = 96\ \text{W} + 86\ \text{W} \quad (2)$$
$$L_{T-R} = 182\ \text{W}$$

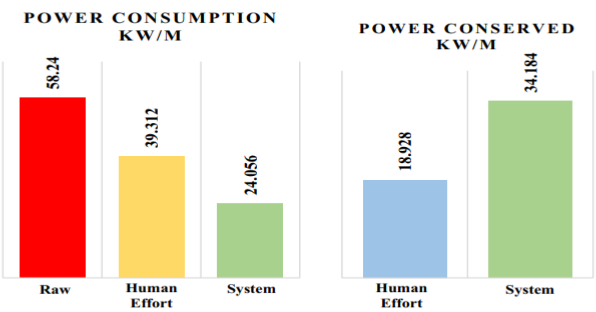


Fig. 12 Power consumption and conservation statistics

As rooms of both faculty members are identical in load so, LT will be double of LT-R.

L Tube =24W
LF= 86 W
LT = 02 × LT−R
LT = 02 × 182
WLT= 364 W

VI. CONCLUSION AND FUTURE WORK

During the research it has been observed that Smart Sockets can be used to provide a smart automation and energy conservation system in any closed environment. Smart socket is designed for monitoring energy consumption and also conserve energy by switching of the unnecessary switches. The utilization of system provided approx. 39% energy conservation in a particular scenario. The system is designed specifically for home purpose but it can also be used for commercial purposes i.e. in offices, universities etc., though it may require multiple Wi-Fi access-points and a dedicated high-end server to connect all Smart Boards in a large-scale environment. In future, the sleek and handy design is planned so the real implementation may be accomplished in a home environment. The new design is planned to be commercialized.

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